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The development of renewable energy in resource-rich region: A case in China

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ABSTRACT

With the largest population living in rural areas, the lack of clean energy supply is an important problem in China, and the utilization of renewable energy not only meets the demand of energy, but also provides a basis for environmental protection and sustainable development. This paper reviews use of clean energy in a resource-rich region, including the basic principle of the development of recycling agriculture, the potential, the present status and the future of renewable energy in the region rural areas. If the project will be finished, there will be 300,000 families benefiting from it and it can bring at least 2.2×10^8 US dollars revenue increase directly, the indirect revenue increase will be 0.15 billion US dollars, the environment will be improved and the living standard in Jincheng's rural areas is also be greatly improved because of developing biogas project. Based on the developing status and constraint conditions, the solutions to further promote renewable energy projects in this region are also proposed.

Contents

1. Introduction

The lack of energy supply in rural areas is a typical problem in developing countries [1], as the largest developing country in the world, China face the same problem [2]. And in rural areas, the

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issues is much serious, firstly, because of the China's development strategy, the energy problems in rural areas have not been fully considered in the past decades, secondly, the energy structure in China rural areas decides that it will bring environmental and social problems.

As the bulletin of national agricultural census showed over 60% of cooking energy are firewood and agricultural residues, even though large amounts of small-scale bio-energy projects were carried out in China's countrysides [3]. Because of the lack of commercial energy supplies, primary energy sources are used for daily cooking and domestic heating in the rural areas, even in the resource-rich areas, only 0.7% households use biogas to cook, in the central and western areas of China, the coal gas & natural gas accounts only about 3.8% and 3.2% [4]. There are much agricultural residues produced in China every year, but large parts are ineffectively used or wasted [3]. If these agricultural residues can be transformed into biogas according to the status quo, it can generate 311.5 billion cubic meter biogas which can solve the shortage of energy in rural areas well [5], and if biomass is used effectively, that can solve the environment problems in great extent. There are about 2.61 billion tons of livestock and poultry waste produced in China [6], but most of them cannot be treated by science technology, what is worse, it stinks around the farm and spoils the ambient environment, moreover, the smoke produced by burned straws always not only affects human health but also affects the flight safety [1,7,8].

With the largest population in countryside and the development strategy changed in recent years, an escalating interest has been emerging for the analysis of rural energy issues in China [9]. The energy consumption and main characteristics [6–9], the development of biomass and another renewable energy system as well as its potential development [3,10], the lessons [11] and the effects [12] of developing bio-energy have been studied. However, the case studies analyzed the final results of development, however the ways to develop renewable system and their models have not been mentioned. In this paper, a developing sustainable energy system in the countryside of Jincheng City, Shan xi Province in China will be presented. The system developing in Jincheng and the benefits from this system will be analyzed.

2. Description of the study area

Jincheng is located in the northeast of Shanxi Province, which is a very important energy producing Province of China, at 110°55′–113°37′E and 35°11′–36°04′N. The population of Jincheng is 2.15 million and 75.7% is rural population, but the GDP of agriculture is only 8.86% of gross domestic product (GDP), and per capita income of farmer is 4435 Chinese Yuan [13].

The landscape in Jincheng is mainly mountainous and hilly terrain, the mountains and hills account for about 87% of all the area. As a resources-based city, Jincheng is fairly rich in resources, iron and coal resources are the richest categories of all resources, and since ancient times it known as the "iron and coal town". Being rich in iron and coal resources supports the city's socio-economic development, but also brings great pressure to the ecological environment and leads environment degradation. As shown in Table 1, the damage to the local ecosystem was huge, the land area damaged by mining was about 2.2% of all the region area, and pollution to soil and water was 110.71 ha and 40.72 ha respectively until 2000.

The local government has realized the problem, to prevent the situation becoming worse and to make it become sustainable development, they began to adopt the circular economy (CE) theory to guide the economic development. CE was introduced to China to address environment degradation and resources scarcity associated with rapid economic development [14,15]. CE principles are applied in the plan of developing economy, society and environment in Jincheng. The local authority takes many effective actions to push the plan, and in the energy aspect, they decided to develop the renewable energy to reuse materials in order to save resource and reduce pollution.

Table 1
Ecological damage caused by mining in Jincheng.

Index	NME	NCME	TLAD (ha)	SPA (ha)	WPA (ha)
1986	1494	952	1566.35	86.26	35.62
2000	1196	799	2057.27	110.71	40.72

NME: number of mining enterprises; NCME: number of coal mining enterprises; TLAD: total land area damaged by mining over the years; SPA: soil pollution area caused by mining; WPA: water pollution area caused by mining.

The strategy to change the way of economics growing has got some marked results. Around the year 2007, Chinese government started Circular Agriculture Demonstration Projects in rural areas, that selecting 10 areas which the circular agriculture develop the best and most representative in China to start the program, and Jincheng became one of the ten demonstrative regions, because they had implied the circular economic theory in the development of agriculture, moreover their development of straw and methane gas projects in Jincheng is the best in China.

The data about Jincheng used in this paper comes from the relevant documents and plans [16–18] of the agriculture bureau of Jincheng, the China Statistical Yearbook, and official website.

3. Renewable energy developed in Jincheng

3.1. The potentiality of renewable energy in Jincheng

The main ideas of Jincheng's circular agriculture development is as shown in Fig. 1. There are four recycling lines in the circular agriculture system, in this paper, we will analyze the line of clean energy and line of resource's recycling. They are the main characteristics of circular agriculture developed in Jincheng. The core of the two lines is the renewable energy, by using the crop straw and livestock manure to produce biogas then use the biogas slurry and biogas residue to stimulate the production of crop. The biogas produced in the system, can be used for daily living energy, livestock raising energy, green house heating energy and electricity generating. At the same time, they also develop some other clean energy, such as solar energy and hydroelectric power, and the energy produced in these systems are all used in living and producing system.

The arable land in Jincheng is 1.92×10^5 ha, the crops area is more than 2.2×10^5 ha, and the production of stalk is about 1 million tons. In 2007 the crop stalks is 1.2×10^6 tons and the livestock manure and human excreta is 2.9×10^6 tons. In China, the main approaches to straw utilization are papermaking, forage, rural energy resource, and recycling in field and collection (including some losses), and the function of being rural energy accounted for 53.6% [19], while in Jincheng only 52.6% crop stalks were comprehensively utilized, the others was burnt directly or discarded in the field and only 0.5% was used as living energy.

In Jincheng, per 8 cubic biogas digesters can meet the living energy demand of a 3–5 people family. If the crop stalks, livestock manure and human excreta can be effectively transformed to biogas, it will meet the energy demand of rural area very well, so there is much potential capacity to develop biomass gas in Jincheng.

3.2. The present status of renewable energy in Jincheng

Since the 1990s, household biogas construction has been developed rapidly in rural China [20]. There are mainly five models of straw gasification and biogas in Jincheng: to develop household

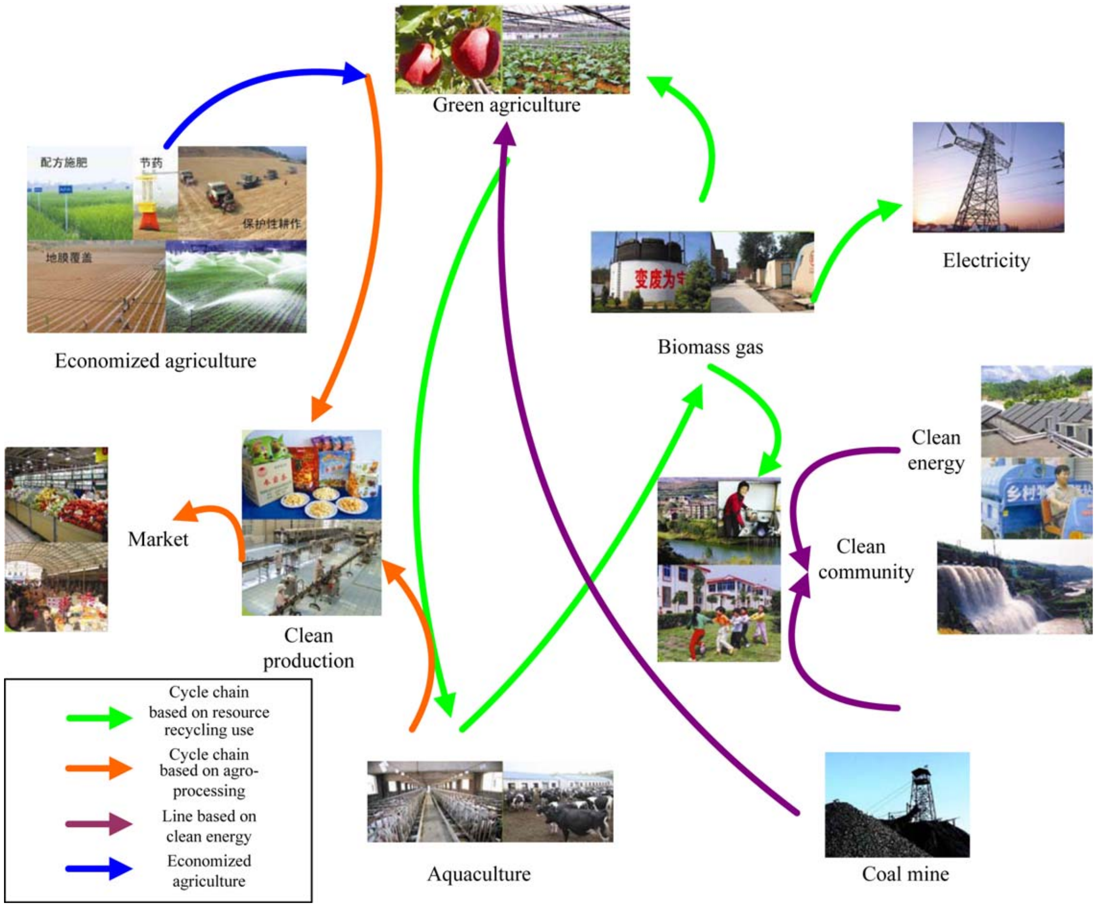


Fig. 1. Circular agriculture system in Jincheng.

biogas in the under developed areas, where the retail culture prevails, there are about 40,000 households at present. Over 80% households in more than 200 villages of this kind use biogas; develop integrated gas supplying projects in the cell culture areas, one of which can supply gas for 3–5 households. There are more than 5000 households benefiting from this model; in developed area, with rich straw resource, focusing on the development of straws gasification projects. In 2000 Jin Cheng established the first straw gasification station, and it has been running well, which plays an exemplary role in the city's construction of straw gasification. By the end of 2006, there were 25 gas gasification stations, around 7000 households benefited from them, till now, there are 96 straw gasification stations and the benefited households are over 36,000; in economically developed regions, where large-scale farms are widespread, develop large and medium-sized biogas projects, 156 large and medium-size biogas stations are in construction and completed. When they are all be completed, there will be about 32,000 households benefiting from them; in the mountainous areas which are relatively underdeveloped and weak in farming basis, promote the household biogas fermentation of pure straw and straw-generation fuel technology. Until October 2007, there were 101,039 households benefited from renewable energy.

3.3. The future of green energy in Jincheng

As "ShanXi Province Jincheng Recycling-agriculture Construction Planning (2008–2010)" shows that 300,000 households which account for 67% of all the farmers will use clean energy such as biogas, straw gas, solar energy, as shown in Table 2. By 2010, over 80% of the straw and stalks will be comprehensively utilized, and over 80% of the livestock manure and human excreta will be processed and comprehensively utilized, of which 100,000 tons straw and stalks and 700,000 tons manure will be used in biogas.

4. Benefits from biogas

4.1. Economic benefits

It is estimated that after the completion of the project in 2010, it can produce 40,000,000 cubic meters of biogas, 110,000,000 cubic meters straw gas each year. It brings the direct gain of more than 0.15 billion yuan, by using organic fertilizer produced along with methane gas. Biogas digester can improve the quality of agricultural production and reduce the use of coal, chemical fertilizer, pesticides; through the promotion of culture and extension of the agricultural industry chain, there will be an indirect income as large as 1 billion yuan.

4.2. Social benefits

We can make full use of the cattle manure, human excreta, waste water, rural solid waste and agricultural residuals in the

Table 2
By 2010, the green energy projects and benefiting households.

	HB	LMBP	SGP	SGFP	SE	Others
Projects number	–	240	112	18	–	–
Benefit households	65,000	45,000	41,000	14,000	50,000	85,000

HB: households scare biogas; LMBP: large and medium-seize biogas project; SGP: straw-generation fuel project; SE: solar energy; Others include coal-bed methane, and hydropower.

generation of biogas, in order to improve the living environment in rural areas. Meanwhile, it can produce high quality organic fertilizer as byproducts, which can be used in the production of vegetables, first it can reduce the use of chemical fertilizer, second using of biogas slurry can reduce the use of Pesticides, so that the production of safe vegetable will increase. Because using of biogas can reduce the volume of smoke indoor, thus it can result in a cleaner cooking condition, so the life quality in rural areas will be greatly improved, and the construction and maintain of biogas projects can increase the employment in this area.

4.3. Environmental benefits

After the completion of the projects, it can comprehensively utilize 940,000 tons crop straw, 1,400,000 tons cattle manure and human excreta which can save 9,000,000 tons coal each year. It can reduce the greenhouse gas emission by two ways: on one hand, using biogas as energy to replace the fossil fuels can cut down emission of carbon dioxide, on the other hand, via the technology of decomposing manure in producing biogas can reduce the emission of methane. Greenhouse effect of methane is over 20 times stronger than that of carbon dioxide. Methane can release during the manure be exposured, composted or pulled directly spare areas. It is estimated that it will reduce 3,000,000 tons of carbon dioxide emission every year [16], and can effectively reduce the COD, BOD, ammonia and other organic matter content in the sewage of farm, decrease the pollution of manure and sewage to environment.

5. Challenges and solutions

5.1. Challenges

Despite the of renewable energy develop very well in Jincheng, and the government also encouraged to develop clean energy by the means of direct subsidies and vigorously promotion of the convenience of biogas, etc. There are still some challenges to the further development of renewable energy.

5.1.1. Economic barriers

The cost of building and maintaining the biogas projects are an obstacle in the development of biogas [21], and it would lead some problems. Even though every household which built one biogas digester can get 1500 yuan subsidies from government, the households and the villages should invest about 2000 yuan. As the price of the materials used in biogas digesters rose, for example the price of brick doubled, and the wages of workers rose 40%, so the cost to build a biogas digester increased more than 800 yuan, but the subsidies stayed. And in some poor hilly areas, the farmers cannot afford the other part needed to build a biogas digester, because they live in the hilly areas, the cost to transport the materials is very high, so the lack of money is a critical barrier to the further development of biogas in Jincheng.

5.1.2. Technical shortcomings

Pyrolysis gasification technology which is applied in rural areas was designed and developed 20 years ago. Too much attention was paid to lower costs, by using a simple structured equipment which requires labor-intensive operation [3]. Some advanced bio-energy technologies developed in Western countries are too expensive for rural areas in China [3,21,22]. Even though some institutes and the government are making efforts to solve the problem, but for most the rural areas of Jincheng, the biogas digesters were designed simply to the level that only if they could produce gas. First it will impact the efficiency of gasification, second it will cause the issues of secondary pollution [21].

5.1.3. Lack of labor force

In partial rural regions, there are more than 70% labor force go out to work and do business, which also cause some difficulties in developing the biogas. First, they do not have enough labor force to build the biogas digester, they have to employ workers to do the job, it is a big expenditure for some families; second, because the labor force leaves, only the elders and children left in home, they do not need use so much energy, so they may only use coal or some other materials as living energy; third, it earns more for the labor force to work in city, so they prefer the commercial energy. Forth, in some villages, as the price of piglets is too high, which increases the risk of feeding, the lack of green feed and the disappeared labor force lead the declining free-rang farmers in rural areas year by year. It directly impacts the supply of materials of biogas production, because of less culture and farming.

5.2. Solutions

5.2.1. Increase the subsides and other support policy

Jincheng is the demonstrative region of recycling agriculture, it has great social, economic and environmental benefits. Green rural energy as an important way of circular agriculture, more governmental subsidies and other supportive policies, such as, tax reduction and low interest loan should be given for the further improvement [3]. Even the subsidy from central government is limited, the local government can make some policies to attract private capital and foundations to participate in the biomass gasification projects.

5.2.2. Develop more forms of clean energy

The local government can promotes hydroelectric and household biogas fermentation of pure straw and straw-generation fuel technology and solar energy in the relatively underdeveloped areas with weak farming basis. Because Jincheng is rich in coal, there are much coal-bed gas produced each year, and the gas always be pumped to the city, so the outskirts of the city and the villages along the coal-bed methane gas lines can utilize coal-bed methane. The local government should develop various means to meet the green energy demand in rural areas.

5.3. Research and introduce biogas technologies suiting for Jincheng

The government should cooperate with the research institutes, for example, China Agricultural University, Shanxi Agricultural University and other colleges to research the technologies that are fit for the condition of Jincheng, and strengthen the technical training for farmers in order to introduce the advanced technologies better.

6. Conclusion

The development of renewable energy in resource-rich area is discussed. Jincheng's development in biogas gasification is very well, by the end of 2010, there will be 300,000 households which accounts for about 67% of all the rural areas that benefit from the clean energy. It can produce 40,000,000 cubic meters of methane and 110,000,000 cubic meters of straw gas each year. It can directly increase revenue more than 0.15 billion yuan and the indirectly increase will be as large as 1,000,000,000 yuan. There will be 940,000 tons crop straw, 1,400,000 tons cattle manure and human excreta comprehensively utilized, which can save 9,000,000 tons coal and reduce 3,000,000 tons emission of carbon dioxide every year. The development of green energy can improve the living standard in Jincheng's rural areas greatly. Even it has made great success, but there are still some challenges, for example economic barriers and technology shortcomings, to promote the bio-energy further in this area, more work need to do.

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References

[1] Wang XH, Feng ZM. Sustainable development of rural energy and its appraising system in China. Renewable and Sustainable Energy Reviews 2002;6:395–404.
[2] Liu H, Jiang GM, Zhuang HY, Wang KJ. Distribution, utilization structure and potential of biomass resources in rural China: with special reference of crop residues. Renewable and Sustainable Energy Reviews 2008;12:1402–18.
[3] Han JY, Mol Arthur PJ, Lu YL, Zhang L. Small-scale bioenergy projects in rural China: lessons to be learnt. Energy Policy 2008;36:2154–62.
[4] Nation Bureau of Statistics of China. The second bulletin of national agricultural census. Available at: http://www.stats.gov.cn/tjgb/nypcgb/.
[5] Sun YM, Li GX, Zhang FD, Shi CL, Sun ZJ. Status quo and developmental strategy of agricultural residues resources in China. Transactions of the CSAE 2005;21(8):169–73 [in Chinese with English abstract].
[6] Sun ZJ, Sun YM. Situation and development of agricultural residues as energy resource utilization in rural areas in China. Transactions of the CSAE 2006;8(1):6–13 [in Chinese with English abstract].
[7] Li JJ, Zhuang X, Delaquil P, Larson Eric D. Biomass energy in China and its potential. Energy for Sustainable Development 2001;5(4):66–80.
[8] Zeng XY, Ma YT, Ma LR. Utilization of straw in biomass energy in China. Renewable and Sustainable Energy Reviews 2007;11(5):976–87.
[9] Zhang LX, Yang ZF, Chen B, Chen GQ, Zhang YQ. Temporal and spatial variations of energy consumption in rural China. Communications in Nonlinear Science and Numerical Simulation 2009;14(11):4022–31.
[10] Zhou ZR, Wu WL, Wang XH, Chen Q, Wang O. Analysis of changes in the structure of rural household energy consumption in northern China: a case study. Renewable and Sustainable Energy Reviews 2009;23:187–93.
[11] Wang XH, Di CL, Hu XY, Wu WM. The influence of using biogas digesters on family energy consumption and its economic benefit in rural areas-comparative study between Linanshui and Guichi in China. Renewable and Sustainable Energy Reviews 2007;11:1018–24.
[12] Tian S, Gill R. Developing effective policies for the sustainable development of ecological agriculture in China: the case study of Jinshan Country with a systems dynamics model. Ecological Economics 2003;53:223–46.
[13] Wang XH, Feng ZM. Biofuel use and its emission of noxious gases in rural China. Renewable and Sustainable Energy Reviews 2004;8:183–92.
[14] Geng Y, Zhu QH, Doberstein B, Fujita T. Implementing China's circular economy concept at regional level: a review of progress in Dalian, China. Waste Management 2009;29(2):996–1002.
[15] Liu Q, Li HM, Zuo XL, Zhang FF, Wang L. A survey and analysis on public awareness and performance for promoting circular economy in China: a case study from Tianjin. Journal of Cleaner Production 2009;17:265–70.
[16] Shanxin Province Jincheng recycling-agriculture construction planning. Unpublished report, August 2008 [in Chinese].
[17] Guidelines for developing recycling-agriculture in Jincheng. Official documents July 2008 [in Chinese].
[18] Report of the development of recycling-economic in Jincheng. Unpublished report, October 2007 [in Chinese].
[19] Zhang PD, Jia GM, Wang G. Contribution to emission reduction of CO_2 and SO_2 by household biogas construction in rural China. Renewable and Sustainable Energy Reviews 2007;11:1903–12.
[20] Gautam R, Baral S, Herat S. Biogas as a sustainable energy source in Nepal Present status and future challenges. Renewable and Sustainable Energy Reviews 2009;13:248–52.
[21] Leung Dennis YC, Yin XL, Wu CZ. A review on the development and commercialization of biomass gasification technologies in China. Renewable and Sustainable Energy Reviews 2004;8:565–80.
[22] Bridgwater AV, Beenackers AACM, Spaila K, Yuan ZH, Wu CZ. An assessment of the possibilities for transfer of European biomass gasification technology to China. Belgium: European Community; 1999.